PRELIMINARY RESULTS FROM A COMPARATIVE MAPPING ANALYSIS IN THE TINTIC MINING DISTRICT USING AVIRIS AND ESSI-PROBE 1 DATA

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1. INTRODUCTION

1.1 Overview and Objectives

In 1998, Earth Search Sciences, Inc. (ESSI) began commercial surveys using PROBE 1, a 128 channel, 0.4 to 2.5 μm, gyro-stabilized hyperspectral sensor built by Integrated Spectronics Propriety Limited.

As part of the 1998 Utah Abandoned Mine Lands (AML) AVIRIS Watershed Analysis Project, EPA Region 8 encouraged participation by private sector remote sensing companies to demonstrate detection and analytical systems which could be utilized in future watershed analysis projects.

On August 28, 1998, ESSI completed fourteen PROBE 1 flight lines over the Oquirrh Mountains and Tintic Districts using a light, twin engine aircraft. At the altitude flown in this survey, PROBE 1 data has 5 meter pixels which is a significantly finer spatial resolution than the 17 meter pixel AVIRIS data collected using the ER-2 aircraft.

Results of a preliminary comparative analysis are presented here:

- To compare the spectral and radiometric characteristics of PROBE 1 and AVIRIS data collected over the same region.

- to illustrate the benefit of using PROBE 1's high spatial and spectral resolution data in the discovery phase of an AML watershed analysis project and

- to demonstrate that indicator mineralogy relevant to AML studies are readily recognizable in PROBE 1 data.

1.2 Role of Remote Sensing In AML Watershed Analysis

The Mine Waste Characterization Project (MWCP) of the U.S. Geological Survey Mineral Resources Program in collaboration with the Abandoned Mine Land Initiative have projects that use a watershed approach to define processes that mobilize metals from mine-waste dumps (Smith et al, 1998).

The MWCP describes the problem and their approach as follows:

> "Release of dissolved metals, acidity, and suspended particulates from solid mine waste to receiving waters is a potentially serious and long-lasting environmental problem. Metal release and acid production depend on the mineralogical, chemical, and physical characteristics of the mine waste as well as geochemical and microbial processes. We use an integrated approach to mine-waste dumps and mill tailings. We combine bulk chemical, physical, and mineralogical characterization with geochemical leaching and weathering studies, microbiological studies, geophysical studies, toxicological studies, and geochemical modeling to determine processes controlling generation, release, and toxic effects of effluent from abandoned mine-waste material. **We are integrating these data with imaging-spectroscopy data to refine remote-sensing techniques for <u>locating and prioritizing</u> mine-waste sites.** Field and laboratory geophysical measurements are being used to determine the extent of the waste and to characterize the waste material at depth to complement the imaging-spectroscopy and geochemical analyses of surficial material.
>
> The MWCP is an interdisciplinary project with the goal of developing methods and tools for solid mine-waste site characterization. Researchers from a variety of disciplines, including geochemistry, geophysics, analytical chemistry, geology, and geomicrobiology, work together at selected mine-waste sites to evaluate the usefulness of diverse approaches and characterization methods. We also aim to understand processes that control the environmental impact of solid mine-waste systems. **An integrated "tool kit" for the characterization and evaluation of abandoned solid mine-waste sites is an objective of this project.** "
> (Smith et al, 1998).

In summary, imaging spectroscopy remote sensing in AML watershed analysis would be part of an integrated toolkit where its primary role would be to **locate and prioritize** mine-waste sites.

2. METHOD

2.1 Study Area

The 57 square kilometer study area extends from 39.88N to 40.03N and 112.09W to 112.13W. (Figure 1). PROBE 1 data is from Strip 98082813 , full scanlines 821 to 4030 and AVIRIS data is from Run 6, Strip ID # F980805-T01P01_R06, eastern one third of lines 140 to 945.

The study area is centered on the town of Eureka, Utah. The area was selected because it has both PROBE 1 and AVIRIS coverage and includes both relatively undeveloped rural land and developed rural land which includes the Main Tintic Mining District. North of Eureka, the terrain is relatively mountainous, partly forested and un-developed compared to the study area's southern half. This northern area serves as a "blank sample" for comparison to the main area of interest, the Main Tintic Mining District.

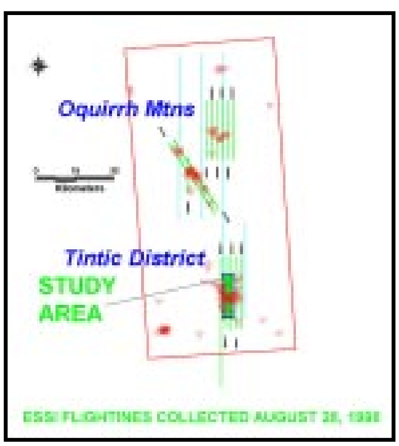

Figure 1

2.2 Previous Work

Immediately adjacent the study area is the East Tintic District which was evaluated using data from an early airborne multispectral survey that spanned the full visible to short wave infrared reflective spectrum (Rowan and Kahle, 1982).

More recent applied studies of airborne spectroscopy for mineral development characterization and evaluation include USGS projects at the Summitville mining district, Colorado (King et al, 1995), the California Gulch Superfund Site, Leadville, Colorado (Swayze et al, 1996, 1998) and the Ray Mine, Arizona (Clark et al, 1998). These studies successfully identified direct and indirect indicator minerals relevant to AML characterization and evaluation. The indicator minerals identified using AVIRIS data include: jarosite, goethite, hematite, schwertmannite, ferrihydrite, amorphous iron hydroxide, kaolinite, montmorillonite, and muscovite (sericite).

Like AVIRIS, PROBE 1 has the spectral resolution necessary to identify these indicator minerals. Distinctive features of these minerals in library spectra are readily identifiable in spectra convolved from AVIRIS and PROBE 1 band centers (Figure 2).

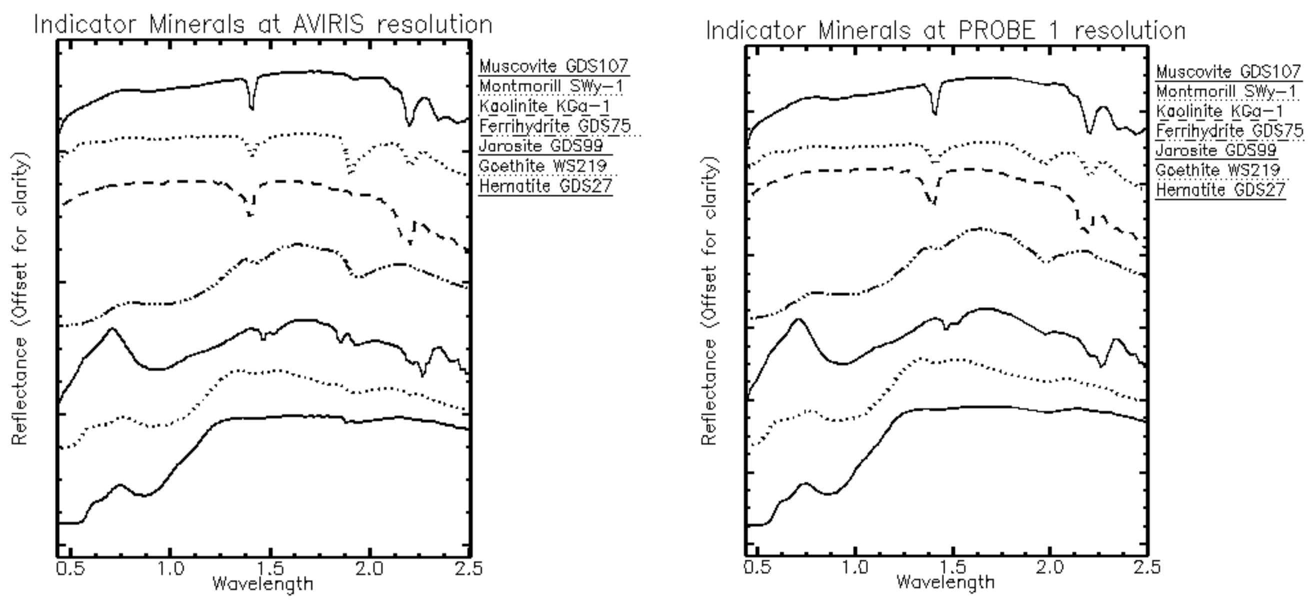

Figure 2: Comparison of AVIRIS and PROBE 1 convolved spectra.

Equally important for timely characterization and evaluation is high resolution spatial data. PROBE 1 is optimally designed to continuously collect 5 to 10 meter pixel data with respective swath widths of 2.5 km and 5 km using a light twin engine aircraft. Finer resolution in continuous mode is possible in slower flying aircraft and sub-meter spectral sampling is mainly limited by safe terrain clearance.

Mine wastes generally occur near their source mine or mill. Watershed contamination from these mine wastes may develop from a combination of physical and chemical dispersion. Mine waste from abandoned mine lands is an opportunistic aggregate supply that in many cases may have been used in road construction or as landfill. Contamination related to drainage may follow narrow watercourses or the contamination indicator minerals may only be visible as coatings on the drainage banks. Therefore mine waste contaminated roadbeds, drainages and point sources are best mapped using high spatial resolution image data.

2.3 General Geological Setting of the Main Tintic Mining District

The following geological summary was derived from a compilation of development history and geological observations from the first century of mining in the Main Tintic District (Morris, 1973).

The Main Tintic Mining District was developed from 1869 until 1957. At least until the early 1970's, the Main Tintic District was the third-ranking mining district in Utah having produced 13.5 million tons of silver, lead, copper and zinc ores.

Essentially all the ores were produced from a 16 square kilometer area extending southward from Eureka through Mammoth to Silver City. The mines were mainly developed on large, irregular replacement orebodies in folded and faulted Paleozoic carbonates adjacent a Tertiary igneous complex. Fracture controlled mineralization extended from within the intrusions and volcanics into the replacement ores.

Ores consisted of native silver and gold plus sulfides and sulphosalts of silver, lead, copper, iron, zinc, cadmium and bismuth associated with jasperoid, barite, quartz, calcite, dolomite and ankerite. Primary orebodies were partly to wholly oxidized down to the perched water table which was 100-650 feet deep in igneous rocks and 1650 to 2400 feet deep in the sedimentary rocks.

Wallrock alteration adjacent ore veins is zoned with inner quartz-sericite-pyrite zone, an argillic envelope (kaolinite, endellite-halloysite, dickite) and an outermost propylitic envelope (less kaolinite, montmorillonite, epidote, chlorites and carbonates).

Mine dewatering was unusual in the Main Tintic District because the water table around the orebodies was perched. Mine waters could be discharged into caverns at lower levels without these waters re-entering the workings or breaching the surface.

2.4 Environmental Characterization of Study Area

The Main Tintic District provides an opportunity for well controlled ground studies that can assess the environmental impact of surface mine waste in isolation from other major contamination factors commonly present in other mining districts.

Unique features of the Main Tintic Mining District:

- **Oxidized base metal sulfide mine wastes with remnant sulfides:** Most of the original carbonate-hosted sulfide mineralogy was naturally deeply oxidized in situ. Resultant acid generation resulted in dissolution within the carbonate host rocks and the development of deep caves. Some metals mobilized from oxidized sulfides were redeposited within enriched ores. Environmental studies could focus on the impact of remobilization of metals from oxidized mine waste by current oxidation of remnant sulfides in surface mine wastes.
- **Historical acid mine water disposal practices:** During the development of the mines, acid mine waters naturally generated and promoted by underground development of sulfide ores were not pumped to surface where long term drainage contamination could have resulted. Drainage contamination analysis is therefore simplified to tracing contamination from surface mine waste sources.
- **Numerous, small, point source mine waste sites:** The first century of mining in the Main Tintic District was from numerous mineshafts accessing the underground developments. High ore to waste ratios of materials brought to surface resulted in less waste material at surface (ie: potential contamination sources). Smaller mine waste deposits near these numerous mineshafts consequently require fine spatial resolution remote sensing to initially locate, evaluate and prioritize remediation efforts.
- **Contrasting host rocks:** About 90% of the mining district's structurally controlled base metal sulfide ores were carbonate hosted however the balance of mineralization and ores hosted in Tertiary igneous rocks were much less oxidized. Environmental studies on the effects of this less oxidized mineralization at numerous sites in the southern part of the mining district (ie: the large open pit at the Dragon deposit) may be compared to the studies on the effects of mine wastes in the rest of the mining district.

2.5 PROBE 1 Data Collection and Analysis

Fourteen lines were collected using PROBE 1 over the Oquirrh Mountains and Tintic District, Utah on August 28, 1998. The complete collection is 9.5 megabytes from 376 line kilometers comprising 76,884 scan-lines.

PROBE 1 flight-line 98082813 was collected from 20:27:27 to 20:33:54 Coordinated Universal Time flying at 141 knots from south (112.1144W, 39.8412N) to north (112.1148W, 40.0936N) at an altitude of 4462 meters. Surface elevations within the study area range from about 1800 meters to 2413 meters. Terrain effects result in pixel sizes from about 4.7 to 5.6 meters and swath widths within the range 2.4 to 3.2 kilometers. Scan rate was 14 hertz. Scan rate, terrain and aircraft speed resulted in scanline overlaps from -1% to 28%. Scanline undersampling was limited to the uppermost 30 meters of Eureka Peak (altitude: 2413 meters).

Raw data was first dark current corrected using a strip average of dark channels 2 to 10. Spectral analysis was completed as follows by the senior author. Radiometric and spectral calibrations by Integrated Spectronics Pty Limited from April 1998 and November 1998 were adjusted after comparison with atmospheric features to calculate a radiance cube. A modified version of ATREM was used to calculate an apparent reflectance data cube. Residual errors in the ATREM-corrected data cube were eliminated by means of a second stage correction in which a spline was fit over spectrally featureless pixel average. The pixel average from this region was divided into the data and the smooth spline curve was multiplied against the result.

The AVIRIS data was converted to apparent surface reflectance in a similar manner.

Analysis of these data sets was separated into analyses of the VNIR (0.4 to 1.3 μm) and SWIR (1.45 to 2.5 μm) regions. Each spectral subcube was subjected to a principal components transformation. Initial endmember determinations were achieved by successive comparisons of two dimensional scattergrams of the initial PC bands. Extreme pixels data cloud verices were examined to determine if they were "reasonable" endmembers. “Reasonable” endmembers is a somewhat subjective determination made by the senior author on the basis of what materials were likely to occur within the scene. These endmembers were then used in a spectral mixture analysis (SMA) of the datasets. A small number of additional endmembers were determined by examination of the root mean squared error image from the SMA. Class maps were derived by thresholding the results of the SMA.

3. RESULTS

Spatial and spectral comparison of PROBE 1 and AVIRIS data is in progress. Spatial comparisons will initially focus on iron-bearing indicator minerals recognized from PROBE 1 data as broad areas, point sources and along roads.

3.1 Spatial Comparison

PROBE 1 five meter data offers a higher level of image clarity than 17 meter AVIRIS data. This is especially evident for developed areas such as the town of Eureka, Utah (Figure 3) and the Dragon minesite (Figure 4). Single pixel wide roadways and developments plus small mine waste sites denoted by several indicator mineral pixels are examples of the benefits of five meter resolution data. Field investigators can use this fine image detail from the preliminary classification maps in their initial field studies.

3.2 PROBE 1 Spectral Results

Spectral classification maps of mine waste indicator minerals (eg: Farrand, 1997, King et al, 1995; Swayze et al, 1996, 1998, Clark et al, 1998) were derived from PROBE 1 data to locate and prioritize potential mine waste contamination in the Main Tintic Mining District. This assessment is preliminary and is based solely on the spectral data and comparisons to mine descriptions and general geology. These indicator mineral classification maps must be validated by ground studies to complete this initial assessment. Consequently these preliminary results carry a disclaimer that the materials identified may or may not be present as shown. These maps however are based on the PROBE 1's high spatial and spectral resolution which permits accurate and prioritized initial field investigations.

The visible-near infrared based iron classification map (Figure 5) shows jarosite (yellow), goethite (red), type #1 ferric soils (orange), type 2 soils having a flat red slope (purple), vegetation (green) and unclassified (black).

Jarositic pixels are most prominent in an area about one kilometer long and about 200 meters wide within the margin of the Silver City monzonite around the Dragon deposit (Figure 5). The study area has over forty other smaller jarositic occurrences in the Silver City monzonite which are associated with fracture controlled mineralization (ie: Sunbeam deposit). South of Ruby Hollow there are over 18 jarositic occurrences in the Sunrise Peak monzonite. These also correlate to fracture controlled mineralization (ie: Treasure Hill deposit, Laciede deposit). Fracture controlled alteration with sparse sulfides and relatively shallow weathering of Tertiary igneous rocks is the principal reason for the widespread jarositic occurrences in the southern half of the Main Tintic Mining District. Two small jarositic occurrences in the more productive northern half of the Main Tintic Mining District are restricted to probable mine wastes located immediately south of the town of Eureka (between the Eureka Hill, Bullion Beck and Chief #1 deposits) and half a kilometer northeast of Mammoth.

Goethitic pixels are most common in a discontinuous, 20 to 50 meter wide annulus around jarositic pixels at the Dragon deposit (Figure 5). Two other small goethitic occurrences in the Silver City monzonite are about 740 meters (Sunbeam deposit) and 1100 meters south-southwest of the Dragon Deposit.

Type # 1 soils with a ferric iron signature are concentrated in three locations. They occur as an inner core to the jarositic pixels at the Dragon deposit. The most prominent iron features in the northern part of the Main Tintic Mining District are a 500 meter by 500 meter area of ferric soils immediately south of the town of Eureka (associated with minor jarositic pixels between the Eureka Hill, Bullion Beck and Chief #1 deposits) and a 120 meter by 400 meter area located about 800 meters further to the southwest (near the former Centennial Eureka deposit). Also notable is the ferric signature associated with the main road running through Eureka.

Type # 2 soils were spectrally mapped based on having a "flat red slope". This classification is quite widespread and probably represents non-vegetated mineral soils. There is no apparent correlation to the bedrock geology or former mineral development sites.

The short wave infrared based alteration classification map (Figure 5) shows kaolinite (red), illite/muscovite (blue), vegetation (green) and unclassified (black). Alteration and sulfide mineralization were commonly formed by the same fracture controlled hydrothermal processes. Consequently mapping alteration can expand on the understanding of potential acid generating sulfidic rocks and mine-wastes.

Illite/muscovite pixels are most common in the Tertiary igneous rocks in the southern Main Tintic District. An illite/muscovite area about 300 meters by 800 meters centered on the Dragon deposit is the most concentrated occurrence in the study area. Other sites throughout the Silver City and Sunrise Peak monzonites are associated with mapped mineralized zones and jarositic pixels. A noteworthy illite/muscovite zone (~120m by 600m) is on the margin of the Packard quartz latite immediately north of the mineralized zones near Eureka.

Kaolinitic pixels are best developed near the Dragon deposit. Three settings are apparent: around the periphery of illite-muscovite pixels centered on the deposit, along a 60 meter wide, two kilometer section of the northern contact of the Silver City monzonite and as small kaolinitic occurrences near mineralized zones within 600 meters of the monzonite contact. Sparse kaolinitic signatures are widespread around mineralized zones in the Sunrise Peak monzonite.

4 CONCLUSIONS

PROBE 1 data has been successfully used to locate and prioritize mine waste contamination mineral indicators in the Main Tintic District for use in preliminary field based assessments. Concentrations and patterns of these minerals indicate field checks should initially focus on the Dragon deposit and probable mine wastes immediately south of Eureka. Comparative studies of these spectral results with recently available AVIRIS data would emphasize the spatial fidelity and relevance of 5 meter versus 17 meter data.

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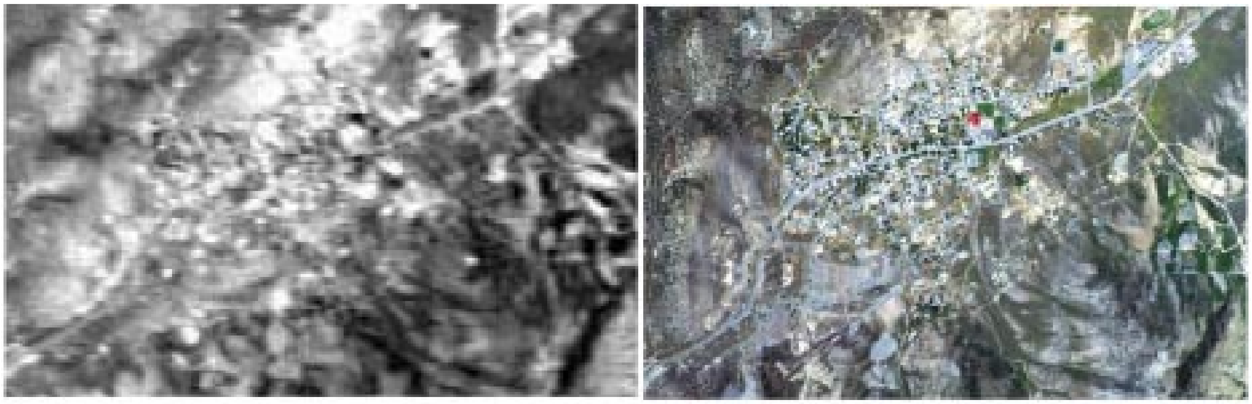

Figures 3a and b: Eureka, Utah. On the left is a panchromatic AVIRIS image with about 17 meter pixels and on the right is the same area in a natural colors PROBE 1 image with about 5 meter pixels.

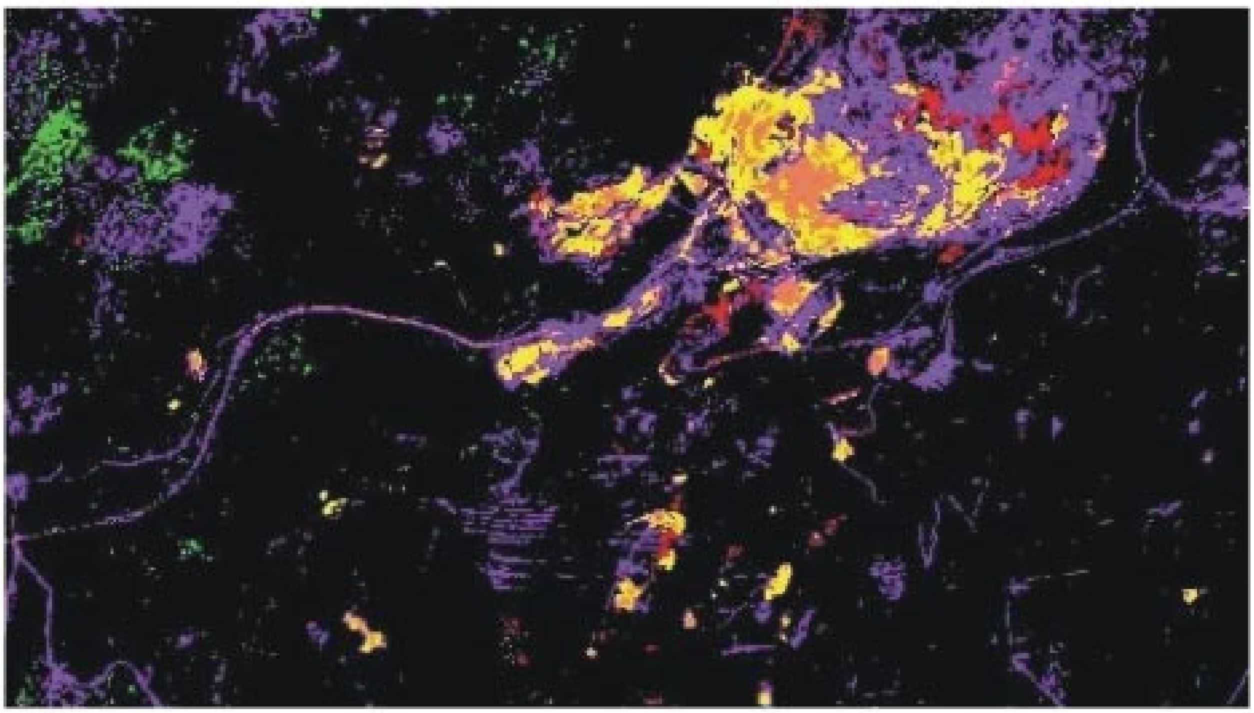

Figure 4: Dragon deposit, Utah. Detail of PROBE 1 classification map derived from visible and near infrared spectra using a spectral angle mapper algorithm. Note several pixel point sources and single pixel linear features.

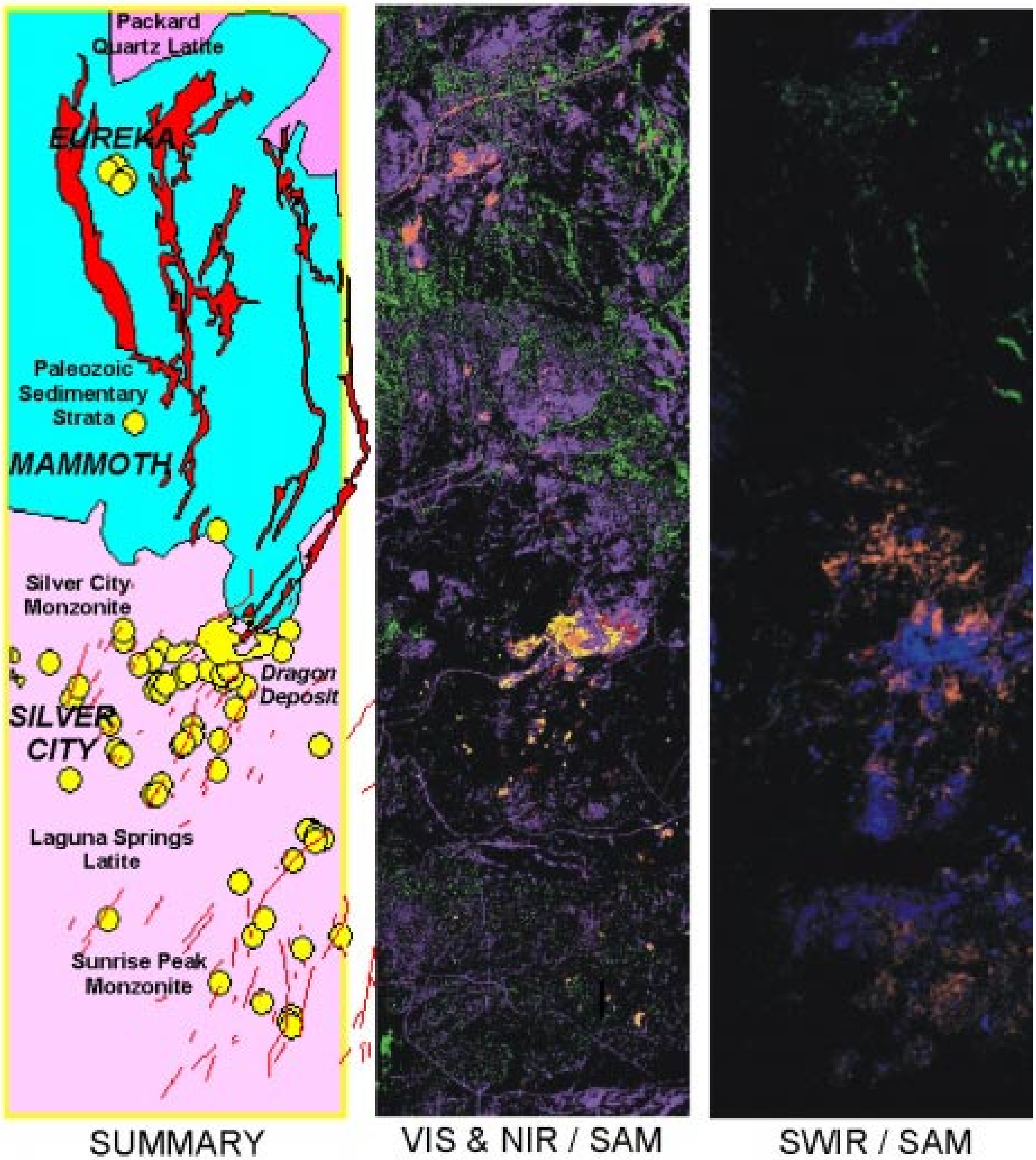

Figure 5: Main Tintic Mining District: Summary diagram at left shows vertically projected mineralization (red) and yellow circles highlight jarositic indications based on a spectral angle mapper classification of visible and near infrared spectra (center image). Classes on the center image are jarositic (yellow), goethitic (red), soil type #1(ferric soils, orange), soil type # 2 (purple), vegetation (green) and unclassified (black). Spectral angle mapper classes from short wave infrared spectra in the imagery on the right are kaolinite (red), illite/ muscovite (blue), vegetation (green) and unclassified (black).